1996

LAKE AND WETLAND MONITORING

PROGRAM REPORT

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Bureau of Environmental Field Services
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Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 43 Kansas lakes and wetlands during 1996. Twelve of these lakes were federal reservoirs, two were major wetlands, and the remaining 29 represented State Fishing Lakes (SFLs)/State Parks and city or county lakes. Two additional lakes were visited, but not sampled, due to low water levels. These two lakes were Augusta City Lake and Olpe City Lake.

The trophic state of most of the surveyed lakes appeared to be stable, as compared to their last surveys. Twenty-six lakes indicated reasonably constant trophic states since their last surveys. Ten lakes indicated an increased trophic state, whereas seven lakes were surveyed in 1996 that indicated an improvement since their last water quality survey. The percentage of lakes with stable trophic status is slightly higher than in past years and can be attributed, at least in part, to the adoption of a special designation for chronically turbid lakes. Phosphorus remained the most common limiting factor for lakes during 1996. Phosphorus was identified as the primary limiting factor in 60% of surveyed waterbodies.

A total of 156 exceedences of the Kansas numeric water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, were documented in the surface waters of the 43 surveyed lakes. Sixty-five (42% of the total) of these exceedences concerned aquatic life support criteria. Fifty-seven concerned water supply, human health (food procurement use), livestock watering, or irrigation criteria.

Atrazine was the most often detected pesticide in Kansas lakes during 1996. Thirty lakes had detectable concentrations of atrazine within their main bodies. These detections ranged in concentration from 0.33 to 9.20 ug/L. Dual (metolachlor) was detected in 18 lakes (concentrations ranging from 0.28 to 14.00 ug/L). Other detected pesticides include alachlor (14 lakes, concentrations of 0.11 to 1.6 ug/L), simazine (one lake, concentration of 0.84 ug/L), cyanazine (two lakes, concentration of 1.6 to 1.9 ug/L), and acetochlor (two lakes, concentration of 0.19 to 0.23 ug/L). In addition, the atrazine metabolite deethylatrazine was detected in 16 lakes. Concentrations of deethylatrazine ranged from 0.30 to 4.40 ug/L.

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INTRODUCTION

Development of the Lake and Wetland Monitoring Program

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, by determining regional and time trends for those impoundments, and by identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses, the number of stations per lake were reduced to a single station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 115 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The program remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in identifying and controlling taste and odor problems, in finished drinking water, that result from lake ecological processes and algae blooms.

Overview of the 1996 Monitoring Activities

Staff of the KDHE Lake and Wetland Monitoring Program visited 45 Kansas lakes during 1996. Two of these lakes were found to have water levels so low as to preclude effective sampling. Of the 43 surveyed sites, twelve are large federal lakes last sampled in 1993 and 1994, nine are State Fishing Lakes (SFLs)/State Parks, twenty are city/county lakes (CLs and Co. lakes, respectively), and two are major wetland/wildlife management areas (WMAs). Twenty-four of the 43 surveyed lakes serve as either primary or back-up public municipal and/or industrial water supplies (PWSs).

As part of the 1996 Governor's Water Quality Initiative in the Kansas/Lower Republican River Basin, seven lakes will be sampled on a yearly basis for the foreseeable future. These lakes include Tuttle Creek, Milford, Clinton, and Perry Lakes that feed into the Kansas River. Also included are three smaller lakes within targeted watersheds in the Black Vermillion River Basin upstream from Tuttle Creek Lake (Centralia Lake) and the Grasshopper Creek Basin upstream of Perry Lake (Mission Lake and Atchison County

Lake).

Table 1 compiles some general information on the lakes surveyed during 1996. Figure 1 presents the locations of the 43 lakes and wetlands visited during 1996. Figure 2 presents the locations of all currently active sites within the Lake and Wetland Monitoring Program. In addition to routine lake monitoring, eleven public lakes, streams, and private ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Created lakes are usually termed "reservoirs" or "impoundments," depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the country, smaller lakes are termed "ponds" based on arbitrary surface area criteria. To provide consistency, this report uses the term "lake" to define all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington, Kansas, has jurisdiction over two lakes. The older lake is called Herington City Lake while the newer lake is called Herington Reservoir in order to distinguish it from its sister waterbody.

METHODS

Yearly Selection of Monitored Sites

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is sampled once during a three year period of rotation. Up to 30 smaller lakes are sampled each year in addition to that year's block of eight federal lakes. These smaller lakes are chosen based on three considerations. (1) Is there recent data available (within the last 3-4 years)? (2) Is the lake showing indications of pollution that require enhanced monitoring? (3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as "ecoregional" reference sites.

Sampling Procedures

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is station 1 for each lake, and should represent the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of inorganic chemistry (basic anions and cations), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, Kjeldahl nitrogen, and phosphorus), and metals (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt,

Table 1. General Information Pertaining to Lakes Surveyed in 1996.

Lake	Basin	Authority	PWS(*)	Last Surveyed
Atchison Co. Lake	KR	Local		new
Augusta Santa Fe Lake	WA	Local	*	1990
Barber Co. SFL	LA	State		1991
Bronson City Lake	MC	Local	*	1992
Butler Co. SFL	WA	State		1991
Centralia Lake	KR	Local		1995
Chanute Santa Fe Lake	NE	Local		1991
Chase Co. SFL	NE	State		1990
Cheney Lake	LA	Federal	*	1993
Clinton Lake	KR	Federal	*	1994
Council Grove Lake	NE	Federal	*	1993
El Dorado Lake	WA	Federal	*	1993
Ford Co. Lake	UA	State		new
Fort Scott City Lake	MC	Local	*	1992
Harvey Co. West Lake	LA	Local		1992
Harveyville City Lake	MC	Local	*	1990
Herington Reservoir	SS	Local	*	1995
Hiawatha City Lake	MO	Local		1992
Hillsdale Lake	MC	Federal	*	1993
John Redmond Lake	NE	Federal	*	1993
Lake Afton	LA	Local		1992
Lake Anthony	LA	Local		1992
Lake Miola	MC	Local	*	1990
Lake Parsons	NE	Local	*	1991
Lone Star Lake	KR	Local		1991
Louisburg SFL	MC	State	*	1990
Marais des Cygnes WMA	MC	State		1993
Marion Lake	NE	Federal	*	1993
Melvern Lake	MC	Federal	*	1993
Miami Co. SFL	MC	State		1990
Milford Lake	KR	Federal	*	1994
Mission Lake	KR	Local	*	1994
Neosho WMA	NE	State		1993
Perry Lake	KR	Federal	*	1994
Pleasanton Reservoir	MC	Local	*	1992
Pomona Lake	MC	Federal	*	1993
Pony Creek Lake	MO	Local	*	new
Richmond City Lake	MC	Local	*	1992
Shawnee Co. SFL	KR	State		1992
Shawnee Mission Lake	KR	Local		1990
Sheridan Co. SFL	SO	State		1991
Tuttle Creek Lake	KR	Federal	*	1994
Wilson Co. SFL	VE	State		1992

KR=Kansas/Lower Republican, LA=Lower Arkansas, MC=Marais des Cygnes, MO=Missouri, NE=Neosho, SO=Solomon, SS=Smoky Hill/Saline, UA=Upper Arkansas, VE=Verdigris, and WA=Walnut.

Figure 1. Locations of the 45 lake and wetland sites visited during 1996 by the KDHE Lake and Wetland Monitoring Program. The 43 sites sampled are indicated by darker symbols. The two sites that could not be sampled are identified by lighter colored symbols.

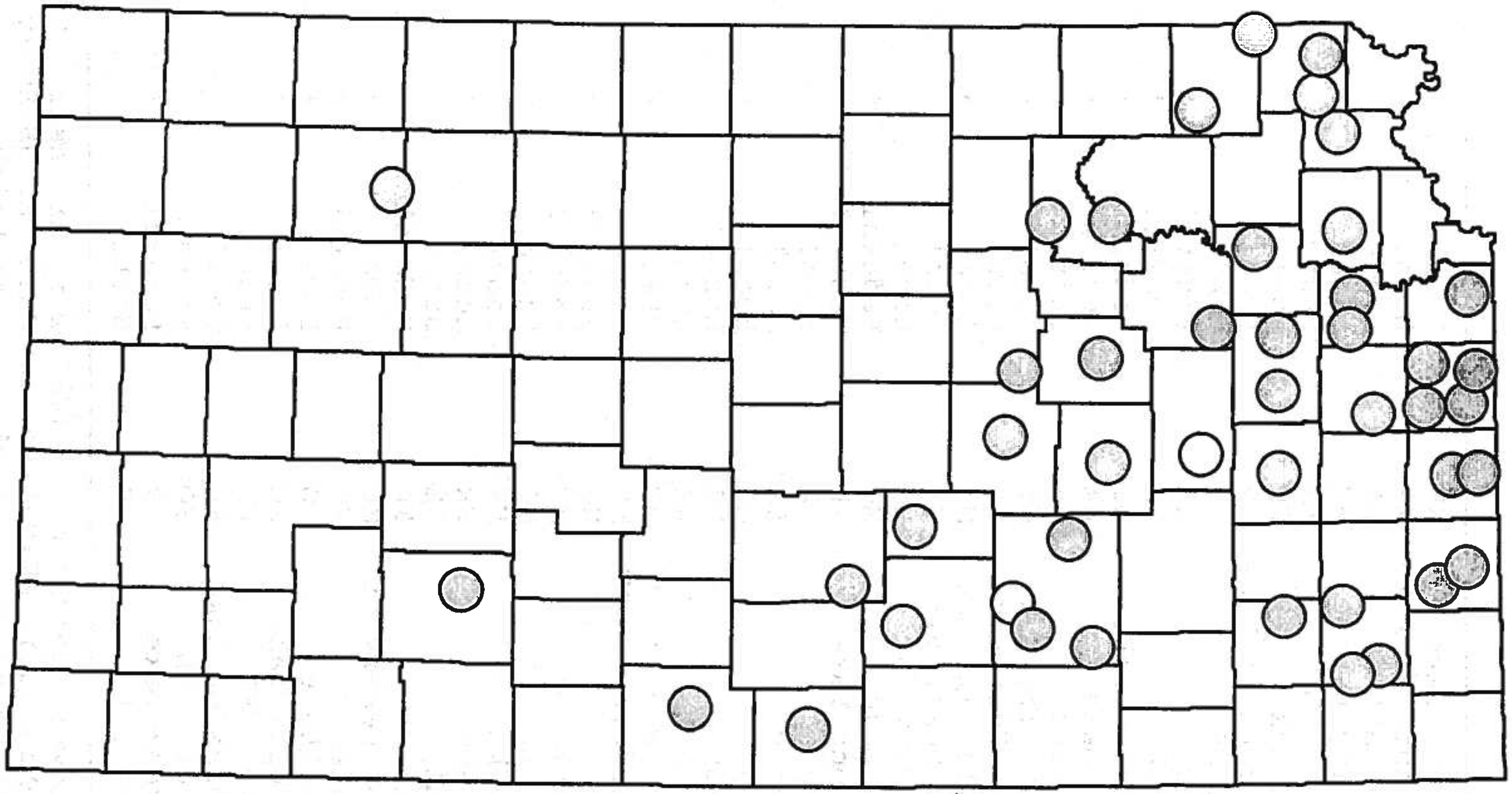
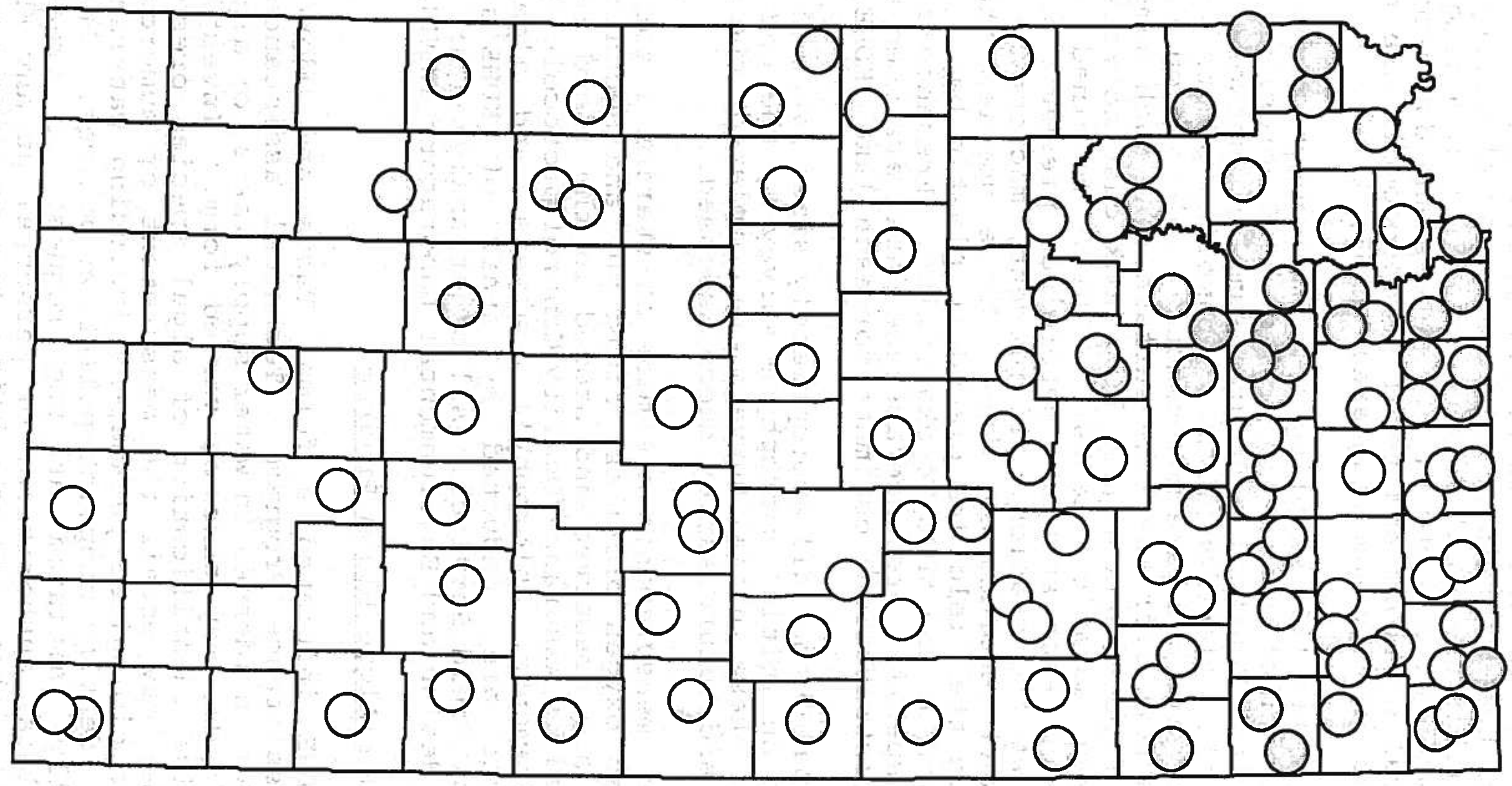


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program.



copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5-to-1.0 meters above the lake substrate for the determination of inorganic chemistry, nutrients, and metals within the hypolimnion. In addition, a single pesticide sample is taken at a depth of 0.5 meters and duplicate bacterial samples (fecal coliform and fecal streptococci) are taken at 0.5 meters at the primary sampling area (KDHE, 1995).

Beginning with the 1992 sampling year, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program sampling network. The survey consists of the selection of 10-20 sampling points (depending on total surface area and lake morphometry), plotted on a field map in a regular pattern over the lake surface. At each sampling point, the boat is stopped and a grappling hook cast to rake the bottom for submersed aquatic plants. This, combined with visual observations at each station, determines presence or absence of macrophytes at the station. If present, macrophyte species are identified and recorded on site. Those species that can't be identified in the field are placed in plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and species specific presence/absence data, are used to calculate a "percent distribution" estimate for each lake (KDHE, 1995).

It is anticipated that all appropriately sized lakes in the program will receive an initial macrophyte survey by the end of the 1997 season. Once these initial surveys are completed, the results will be analyzed and future survey needs assessed.

At each lake, measurements are made at station 1 for temperature and dissolved oxygen profiles, field pH, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE Quality Assurance/Quality Control protocols (KDHE, 1995). Field measurements, chlorophyll analysis, and algal taxonomic determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KDHE, 1995).

<u>Taste and Odor/Algae Bloom Program</u>

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied form. Investigations may simply involve identification of algal species present within a lake, or they may entail the measurement of numerous physical, chemical, or biological parameters including watershed land use analysis to identify nonpoint pollution sources. Investigations are generally initiated at the request of treatment plant personnel, local authorities, or personnel at any KDHE District Office. While lakes used as public water supplies are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both streams and lakes, are accepted for analysis.

RESULTS AND DISCUSSION

Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) remains a useful tool for comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the lakes surveyed in 1996, previous TSI scores for lakes with past data, and an indication of the extent that individual lakes were dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll TSI scores are based on the planktonic algal community, a dominance by macrophytes "bumped" the trophic state classification to the next highest level above that assigned by TSI score alone. The system used to assign trophic state, based on the TSI score, is given below. It represents an in-house modification of the Carlson TSI system to account for macrophytic productivity. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is estimated at greater than 30%.

TSI score of 0-39 = Oligo-Mesotrophic = O/M.

> O/M = A lake with a low level of planktonic algae and no significant macrophyte community. Such lakes also lack significant amounts of suspended clay particles in their water columns, giving them a relatively high level of water clarity. Chlorophyll-a = less than or equal to 2.5 ug/L.

TSI score of 40-49 = Mesotrophic = M.

> M = A lake with only a moderate planktonic algal community, or a small algal community combined with a significant macrophyte community. Chlorophyll-a = 2.51-to-7.2 ug/L.

TSI score of 50-63 = Eutrophic = E.

> E = A lake with a large planktonic algal community or a moderate algal community combined with a significant macrophyte community. Chlorophyll-a = 7.21-to-30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic = SE (Chl-a = 7.21-to-12.0 ug/L),
TSI = 55-59 = eutrophic (i.e., fully eutrophic) = E (Chl-a = 12.1-to-20.0 ug/L),
TSI = 60-63 = very eutrophic = VE (Chl-a = 20.1-to-30.0 ug/L).

Table 2. Current and past TSI scores, and trophic state classifications for the 1996 lakes. The abbreviations used previously for trophic state levels (O/M, M, E, H, and A) apply here. An asterisk appearing after the name of a lake denotes that the lake was macrophyte dominated. In such a case, the 1996 trophic state, based solely on TSI score, is given followed by the macrophyte-adjusted designation in parentheses. As 1996 is the first year lakes have been designated by the argillotrophic class, previous trophic states may be followed by "(A)" to indicate they were impacted by chronic high turbidity.

Lake	1996 TSI	& Status	Previous Status
Atchison Co. Lake	49.8	A	VE (A)
Augusta SF Lake	58.4	E	E
Barber Co. SFL	52.7	SE	SE
Bronson City Lake	60.8	VE	SE
Butler Co. SFL	65.5	H	H
Centralia Lake	65.8	H	H
Chanute SF Lake	69.6	H	H
Chase Co. SFL	47.6	M	M
Cheney Lake	35.2	A	E (A)
Clinton Lake	54.2	SE	E
Council Grove Lake	51.2	A	M (A)
El Dorado Lake	42.8	A	M
Ford Co. Lake	72.8	H	H
Fort Scott City Lake*	47.3	M (SE)	M (SE)
Harvey Co. West Lake	66.6	H	H
Harveyville City Lake	46.9	M	SE
Herington Reservoir	64.0	H	VE
Hiawatha City Lake	57.4	E	H
Hillsdale Lake	54.0	SE ###	E ###
John Redmond Lake	43.8	A	M (A)
Lake Afton	67.2	H	E
Lake Anthony	75.6	H	VE
Lake Miola	54.2	SE	SE
Lake Parsons	40.9	A	M (A)
Lone Star Lake	58.5	E	E
Louisburg SFL	52.5	SE	M
Marais des Cygnes WMA	76.2	H	E
Marion Lake	56.9	E	SE
Melvern Lake	48.1	M	M
Miami Co. SFL	69.2	H	H
Milford Lake	48.2	M	SE
Mission Lake	45.1	A	E (A)
Neosho WMA	76.4	H	H
Perry Lake	52.8	SE	SE
Pleasanton Reservoir	59.5	E	SE
Pomona Lake	39.6	A	M (A)
Pony Creek Lake	68.6	H	VE

Table 2 continued. Current, and past, TSI scores and trophic state classifications for 1996 lakes.

Lake	1996 TSI & Status		Previous Status
Richmond City Lake*	49.1	M (SE)	E (VE)
Shawnee Co. SFL*	48.4	M (SE)	SE (E)
Shawnee Mission Lake	45.3	M	M
Sheridan Co. SFL*	68.6	H (H)	VE (H)
Tuttle Creek Lake	42.9	A	M (A)
Wilson Co. SFL	57.3	E	SE

= Hillsdale Lake represents a special case as the whole-lake TSI, which is given, is the mean of three individual stations within the lake. Overall, this lake currently sits on the boundary between slightly and fully eutrophic.

TSI score of 64 or greater = Hypereutrophic = H.

H = A lake with a very large planktonic algal community or a large algal community combined with a significant macrophyte community. Chlorophyll-a = >30.0 ug/L.

TSI score not relevant = Argillotrophic = A.

In a number of Kansas lakes, chronic, high turbidity due to suspended clay particles controls the development of an algal community. In such cases, nutrient availability remains high, but is not fully translated into biological productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal production (macrophytic growth is normally absent from such lakes), may be called "argillotrophic" (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. The argillotrophic class is identified by the letter "A" within this report.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6-(2.04-0.68\ln(C))/LOG_{natural}(2)).$$

The composition of the algal community often gives a better ecological picture of a lake than relying solely on a trophic state classification. Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 1996. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green species, while those dominated by diatom communities may not be so enriched. Certain species of blue-green, diatom, or dinoflagellate algae may

Table 3. Algal communities present in the 1996 lakes at the time of sampling. "Other," in the far right column, refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellates. Percentages may not add to exactly 100 due to rounding.

Lake	Total Count (cells/mL)	Percent Composition green	bluegreen	diatoms	other
Atchison Co. Lake	756	50	0	0	50
Augusta SF Lake	4,977	71	0	22	7
Barber Co. SFL	15,498	98	0	0	2
Bronson City Lake	27,468	37	60	<1	3
Butler Co. SFL	46,305	65	8	16	11
Centralia Lake	57,015	0	97	3	0
Chanute SF Lake	26,523	6	64	6	24
Chase Co. SFL	1,512	50	42	4	4
Cheney Lake	1,134	83	0	17	0
Clinton Lake	5,418	26	35	37	2
Council Grove Lake	2,898	0	0	100	0
El Dorado Lake	1,890	67	17	7	9
Ford Co. Lake	311,094	<1	99	<1	<1
Fort Scott City Lake	2,835	93	0	2	4
Harvey Co. West Lake	23,184	44	49	<1	7
Harveyville City Lake	5,292	67	24	5	5
Herington Reservoir	18,522	48	34	11	6
Hiawatha City Lake	19,026	90	0	4	6
Hillsdale Lake*	4,158	21	45	30	4
John Redmond Lake	945	47	33	7	13
Lake Afton	62,937	1	98	<1	<1
Lake Anthony	24,822	46	0	13	41
Lake Miola	2,646	62	24	7	7
Lake Parsons	1,071	65	0	18	18
Lone Star Lake	8,913	49	32	0	19
Louisburg SFL	13,734	12	83	2	3
Marais des Cygnes WMA	11,151	22	34	44	0
Marion Lake	5,418	23	52	23	2
Melvern Lake	2,772	27	0	70	3
Miami Co. SFL	54,873	8	92	0	<1
Milford Lake	2,898	15	76	7	2
Mission Lake	252	50	0	0	50
Neosho WMA	26,397	26	0	62	12
Perry Lake	5,607	37	0	53	10
Pleasanton Reservoir	10,521	17	72	9	2
Pomona Lake	819	92	0	0	8
Pony Creek Lake	136,395	<1	99	0	0
Richmond City Lake	12,285	61	31	7	1
Shawnee Co. SFL	3,528	5	71	5	18

Table 3 continued. Algal communities present in the 1996 lakes.

Lake	Total Count (cells/mL)	Percent Composition green	bluegreen	diatoms	other
Shawnee Mission Lake	1,953	65	0	16	19
Sheridan Co. SFL	153,153	11	86	<1	2
Tuttle Creek Lake	693	45	0	55	0
Wilson Co. SFL	1,701	48	0	30	22

* = Hillsdale Lake represents a special case as the whole-lake counts, which are given, are the mean of three individual stations within the lake.

contribute to taste and odor problems, when present in large numbers, in lakes or streams that serve as public drinking water sources.

Table 4 presents biovolume data for the 43 lakes surveyed during 1996. Such data becomes useful, especially when compared to cell count data, in determining which species or algae groups actually exert the most profound impact on the lake.

Trends in Trophic State

Trends in trophic state, among the 43 surveyed lakes, appeared to be mostly stable since the last surveys. Table 5 presents the results of the comparison of current trophic state to past records.

Of the 43 lakes surveyed in 1996, ten lakes displayed increases in lake trophic state (about 23%). Twenty-six lakes remained stable over time (about 60%). About 17% of the lakes surveyed in 1996 show improvement (lower trophic state) since their last surveys. The amount of "stable" lakes is higher than in some past years of reporting. A significant portion of this stability is due to the assignment of argillotrophic status to those lakes with chronic turbidity problems.

As can be seen in Table 6, six of the 12 macrophyte surveys resulted in no macrophytes being found. This may mean that cover was non-existent, or it may merely indicate that macrophyte presence was so sparse as to preclude detection using the current technique. In the six lakes with measurable macrophyte communities, the common plant species were various forms of pondweed (Potamogeton spp.), water naiad (Najas guadalupensis), and stonewort algae (Chara spp.).

Table 4. Algal biovolumes calculated for the 1996 lakes at the time of sampling. "Other," in the far right column, refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellates. Percentages may not add to exactly 100 due to rounding. The biovolume units are calculated in mm^3/L, and expressed as parts-per-million.

Lake	Total Biovolume (ppm)	Percent Composition			
		green	bluegreen	diatoms	other
Atchison Co. Lake	0.775	5	0	0	95
Augusta SF Lake	3.383	40	0	41	19
Barber Co. SFL	5.315	69	0	0	31
Bronson City Lake	9.740	26	30	15	28
Butler Co. SFL	21.656	32	9	36	23
Centralia Lake	12.304	0	70	30	0
Chanute SF Lake	17.201	4	19	17	60
Chase Co. SFL	0.645	55	26	2	17
Cheney Lake	0.787	47	0	53	0
Clinton Lake	4.897	8	8	78	7
Council Grove Lake	7.075	0	0	100	0
El Dorado Lake	1.267	30	2	39	29
Ford Co. Lake	39.411	<1	95	4	1
Fort Scott City Lake	1.685	55	0	29	16
Harvey Co. West Lake	6.797	31	39	2	27
Harveyville City Lake	2.047	40	12	24	24
Herington Reservoir	16.931	17	11	43	29
Hiawatha City Lake	9.720	25	0	16	59
Hillsdale Lake*	3.683	9	15	65	11
John Redmond Lake	0.251	30	17	3	49
Lake Afton	25.003	<1	72	2	26
Lake Anthony	31.278	15	0	5	80
Lake Miola	3.026	36	3	12	49
Lake Parsons	0.849	16	0	41	43
Lone Star Lake	5.610	20	5	0	74
Louisburg SFL	3.722	5	41	1	53
Marais des Cygnes WMA	12.956	66	3	31	0
Marion Lake	6.551	8	6	79	7
Melvern Lake	2.884	4	0	92	4
Miami Co. SFL	11.443	47	52	0	1
Milford Lake	1.298	17	50	25	8
Mission Lake	0.492	50	0	0	50
Neosho WMA	32.361	8	0	61	31
Perry Lake	7.695	8	0	75	18
Pleasanton Reservoir	5.444	23	23	31	23
Pomona Lake	0.226	46	0	0	54
Pony Creek Lake	18.647	<1	99	0	0
Richmond City Lake	3.679	56	23	14	7
Shawnee Co. SFL	2.091	2	15	7	76
Shawnee Mission Lake	2.030	40	0	16	43

Table 4 continued. Algal biovolumes calculated for the 1996 lakes.

Lake	Total Biovolume (ppm)	Percent Composition green	bluegreen	diatoms	other
Sheridan Co. SFL	23.209	9	61	2	28
Tuttle Creek Lake	0.633	7	0	93	0
Wilson Co. SFL	3.506	15	0	45	41

* = Hillsdale Lake represents a special case as the whole-lake values, which are given, are the mean of three individual stations within the lake.

Table 5. Trends over time for lake trophic state classification within each major river basin in Kansas. While three of these lakes were new to the KDHE Lake and Wetland Monitoring Program, past data existed for examining time trends.

Basin	Number of Lakes Constant	Improving	Degrading
Kansas/Lower Republican	7	3	0
Lower Arkansas	3	0	2
Marais des Cygnes	5	3	4
Missouri	0	1	1
Neosho	6	0	1
Solomon	1	0	0
Smoky Hill/Saline	0	0	1
Upper Arkansas	1	0	0
Verdigris	0	0	1
Walnut	3	0	0
Totals	26	7	10

Table 6. Macrophyte community structure in 12 of the lakes surveyed during 1996. Macrophyte community in these surveys refers to submersed and floating-leaved aquatic plants, but not to the emergent shoreline community. The percent species cover is the abundance estimate for each documented species (Note: due to overlap in species cover, the percentages under community composition may not equal the percent total cover.).

Lake	% Total Cover	% Species Cover and Community Composition	
Augusta Santa Fe Lake	<5%	<5%	none
Centralia Lake *	>50%	?%	Potamogeton nodosus
		?%	Potamogeton pectinatus
		?%	Najas guadalupensis
		?%	Polygonum sp.
Chase Co. SFL	5%	5%	Potamogeton nodosus
Ford Co. Lake	<5%	<5%	none
Harvey Co. West Lake	20%	20%	Potamogeton sp.
Harveyville City Lake	<5%	<5%	none
Lake Afton	<5%	<5%	Potamogeton spp.
Lake Miola	<5%	<5%	none
Louisburg SFL	20%	20%	Chara zeylanica
		5%	Nelumbo nucifera
Miami Co. SFL	<5%	<5%	none
Pony Creek Lake	35%	35%	Najas guadalupensis
		35%	Potamogeton pusillus
		20%	Potamogeton nodosus
Shawnee Mission Lake	<5%	<5%	none

* = Centralia Lake falls above the surface area cutoff for routine macrophyte surveys. However, due to the inclusion of the lake as part of the Governor's Water Quality Initiative, and the abundance of macrophytes, a survey will be conducted in 1997.

Lake Stratification

Stratification is a natural process that occurs in any standing body of water, whether that waterbody is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (heat energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser, layer (hypolimnion) remains near the bottom of the lake while the upper layer (epilimnion) develops a higher ambient temperature. The middle layer (metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion.

Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. The net result is no re-oxygenation from the atmosphere within the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to be depleted of oxygen and unavailable for fish and other aquatic life as habitat. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. The fall time of lake mixing is called "lake turnover."

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich hypolimnetic waters with epilimnetic waters that are lower in nutrients and richer in dissolved oxygen. This often results in explosive algae growth, lowering of overall lake dissolved oxygen levels, sudden fishkills, and often imparts objectionable odors to the lake water and tastes or odors to drinking water produced from the lake. Therefore, this lake process is important in lake management, the ability of the waterbody to support aquatic life, and the ability of the waterbody to support sport fisheries.

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. Resultant concentrations largely depend on the strength and duration of stratification, existing lake sediment quality, and the inflow of materials from the watershed.

Sediment re-release of materials, and water quality impact at turnover, would be most pronounced in a deep, moderate-to-small sized lake, with abundant protection from the winds, shallow thermocline, and a history of high pollutant loads from the watershed. For a number of our larger lakes in Kansas, built on major rivers with dependable inflows, stratification tends to be intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be a small portion of the total volume. These conditions tend to lessen the importance of sediment re-release of pollutants in larger Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Presence or absence of stratification is determined by the depth profiles taken in each lake for temperature and dissolved oxygen concentration. Table 7 presents this data. Any temperature change greater than -1.0 degree Celsius per meter depth is considered evidence of strong thermal stratification (Hutchinson, 1957; Wetzel, 1983), although temperature changes may be less pronounced during the initiation phase of stratification. Presence of a

Table 7. Lake and wetland stratification status for the 43 sites surveyed during 1996.

Lake	Date Sampled	Temperature Decline Rate (degrees/meter)	Dissolved Oxygen Decline Rate (mg/L per meter)	Thermocline Depth (meters)	Maximum Depth Recorded (meters)
Atchison Co. Lake	July 9	na	na	none present	1.5
Augusta SF Lake	August 20	-1.67	-0.80	1-2	3.0
Barber Co. SFL	June 17	-2.00	-2.68	1-2	4.0
Bronson City Lake	July 15	na	na	unknown	6.0
Butler Co. SFL	August 20	-0.33	-0.13	none present	3.0
Centralia Lake	July 10	-0.88	-0.73	5-6	8.0
Chanute SF Lake	July 16	-1.00	-3.17	1-2	3.0
Chase Co. SFL	August 1	-0.70	-0.67	7-8	10.0
Cheney Lake	August 21	-0.08	-0.06	none present	12.0
Clinton Lake	August 7	-0.25	-0.62	none present	12.0
Council Grove Lake	August 12	-0.09	-0.04	none present	11.0
El Dorado Lake	June 3	-0.23	-0.41	none present	15.5
Ford Co. Lake	June 18	-1.33	-5.43	1-2	3.0
Fort Scott City Lake	July 17	na	na	unknown	9.0
Harvey Co. West Lake	June 17	na	na	none present	2.0
Harveyville City Lk.	July 31	na	na	unknown	3.0
Herington Reservoir	July 2	-0.56	-1.20	2-3	8.0
Hiawatha City Lake	July 8	na	na	unknown	5.5
Hillsdale Lake *	August 13	-0.42	-0.65	9-11	14.0
John Redmond Lake	June 11	-0.25	-0.40	none present	4.0
Lake Afton	June 17	-0.92	-1.73	3-4	6.0
Lake Anthony	June 17	-1.33	-3.00	1-1.5	1.5
Lake Miola	July 1	-1.38	-0.95	3-4	8.0
Lake Parsons	July 16	-0.36	-0.85	4-5.5	5.5

Table 7 continued. Lake and wetland stratification status for the 43 sites surveyed during 1996.

Lake	Date Sampled	Temperature Decline Rate (degrees/meter)	Dissolved Oxygen Decline Rate (mg/L per meter)	Thermocline Depth (meters)	Maximum Depth Recorded (meters)
Lone Star Lake	June 24	-1.11	-0.97	2-3	9.0
Louisburg SFL	June 25	-1.23	-1.23	3	6.5
Marais des Cyg. WMA	July 15	na	na	none present	<0.5
Marion Lake	June 4	na	na	unknown	8.5
Melvern Lake	June 10	-0.07	-0.14	none present	15.0
Miami Co. SFL	June 25	na	na	unknown	1.5
Milford Lake	August 26	-0.09	-0.40	none present	17.0
Mission Lake	July 9	-0.75	-1.40	3-4	4.0
Neosho WMA	July 16	na	na	none present	0.5
Perry Lake	August 8	-0.25	-0.54	none present	12.0
Pleasanton Reservoir	July 15	-1.33	-1.50	3-5	6.0
Pomona Lake	June 10	-0.20	-0.45	7-9	15.0
Pony Creek Lake	July 8	-1.20	-0.76	3-5	10.0
Richmond City Lake	July 31	-1.22	-0.89	3-5	9.0
Shawnee Co. SFL	July 10	-1.00	-0.78	4-5	9.0
Shawnee Mission Lake	July 1	-2.00	-0.88	2-3	10.0
Sheridan Co. SFL	June 18	-2.00	-2.38	3-4	5.0
Tuttle Creek Lake	August 26	-0.28	-0.42	none present	16.0
Wilson Co. SFL	July 16	-0.67	-0.65	5-7	12.0

* = Hillsdale Lake temperature/dissolved oxygen data is from the primary deep-water station only.

na = Indicates that boat access, wind conditions, shallowness, or equipment problems prevented taking profile data or made its acquisition superfluous.

significant oxycline is also used to determine stratification. Some of the larger lakes, created by impounding major streams, exhibit "polymictic" behavior. In these lakes, stratification may never be very strong, and the water column may stratify and de-stratify several times during the summer, if at all.

Contact Recreation and Fecal Coliform Bacterial Counts

For the past four years, bacterial samples have been collected at swimming beaches, or other appropriate near-shore sites, rather than at the primary sampling station in the lake. In 1996, bacterial samples were again collected from the same deep-water station used for other chemical and biological sampling. This change was precipitated by several arguments. First, as bacterial sampling is most strongly associated with contact recreation (swimming and skiing), and contact recreation is not limited to swimming beaches, a more representative whole-lake assessment was appropriate. Second, the sampling frequency possible for this program is not adequate to truly characterize a localized swimming beach area. Third, many larger lakes tended to have multiple beaches which outstripped scheduled laboratory capacity. Fourth, beach sampling should be the responsibility of the entity that provides the beach. These management entities are in a much better position to conduct adequate sampling, in terms of collection frequency and number of samples.

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform bacteria counts should only occur in the open water of a lake if 1) there has been a recent pollution event, or 2) there is a chronic input of fecal contamination. Given such a setting, a single set of bacteria samples should be sufficient as an indicator of whole-lake bacterial water quality.

Table 8 presents the bacterial data collected during the 1996 sampling season. All counts are compared to the 200 colonies/100 mL standard for contact recreation within the Kansas Surface Water Quality Standards (KDHE, 1994).

Eleven lakes, out of the 43 surveyed, had fecal coliform bacterial counts that averaged above the detection limit. Only one lake exceeded the 200 colonies/100 mL criteria for contact recreation (average of duplicate samples). This lake was Augusta Santa Fe Lake, which had recently experienced a storm event that likely washed bacteria laden material from agricultural land upstream.

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 43 lakes and wetlands surveyed during 1996. Since wetlands are not considered "attainable" for contact recreational use, those values are given for informational purposes only. It should also be kept in mind that these are one time grab samples taken during the week, not during the weekends which should be higher use periods. All units are in "number of colonies per 100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Atchison Co. Lake	near dam	30
Augusta Santa Fe Lake	open water	480*
Barber Co. SFL	open water	<10
Bronson City Lake	near dam	<10
Butler Co. SFL	open water	<10
Centralia Lake	open water	<10
Chanute Santa Fe Lake	open water	<10
Chase Co. SFL	open water	20
Cheney Lake	open water	<10
Clinton Lake	open water	<10
Council Grove City Lake	open water	<10
El Dorado Lake	open water	<10
Ford Co. Lake	open water	<10
Fort Scott City Lake	open water	10
Harvey Co. West Lake	open water	35
Harveyville City Lake	near dam	<10
Herington Reservoir	open water	<10
Hiawatha City Lake	near dam	10
Hillsdale Lake	open water	<10
John Redmond Lake	open water	55
Lake Afton	open water	<10
Lake Anthony	open water	<10
Lake Miola	open water	<10
Lake Parsons	open water	<10
Lone Star Lake	open water	<10
Louisburg SFL	open water	12
Marais des Cygnes WMA	near shore	40
Marion Lake	near dam	30
Melvern Lake	open water	<10
Miami Co. SFL	open water	68
Milford Lake	open water	<10
Mission Lake	open water	35
Neosho WMA	open water	<10
Perry Lake	open water	<10
Pleasanton Reservoir	open water	<10
Pomona Lake	open water	<53
Pony Creek Lake	open water	<10

Table 8 continued. Fecal coliform bacterial counts (mean of duplicate samples) from the 43 lakes and wetlands surveyed during 1996.

Lake	Site Location	Fecal Coliform Count
Richmond City Lake	open water	<10
Shawnee Co. SFL	open water	<10
Shawnee Mission Lake	open water	<10
Sheridan Co. SFL	open water	30
Tuttle Creek Lake	open water	<10
Wilson Co. SFL	open water	<10

* = Augusta Santa Fe Lake experienced a storm event prior to the water quality survey.

Limiting Nutrients and Physical Parameters

The determination of which nutrient, or physical characteristic, "limits" phytoplankton production is of primary importance in lake management. If certain features can be identified, which exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

The concept of limiting nutrients, or limiting factors, is often difficult for the layman to grasp. The following analogy is provided in an attempt to clarify the concept:

> A person is given 10 spoons, 9 knives, and 5 forks. They are then asked to place sets of utensils at each seat at a large table. Further, only complete sets of utensils are to be placed, with a complete set including all three utensils. The question is, "What utensil is the limiting factor?"
>
> In this example, the number of forks available "limits" the number of place settings that can be made. Therefore, forks become the limiting factor for this scenario.

In a lake ecosystem, the level of algal production is the "place setting," while plant nutrients and light availability are the "spoons, forks, etc." Common factors that limit algal production in lakes are the levels of available nutrients (primarily phosphorus and nitrogen) and the amount of light available to power photosynthesis. Less common limiting factors in lakes, and other lentic waterbodies, include available levels of carbon, iron, temperature, and/or vitamins.

The use of nutrient ratios are commonly employed to estimate which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae cells for the different chemical nutrients. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios that are above 12 indicate phosphorus limitation. Conversely, TN/TP ratios below 7 indicate nitrogen limitation. Ratio numbers of 7-to-12 indicate that both, or neither, of these major plant nutrients may be limiting to phytoplankton production (Wetzel, 1983). The 1992 season marked the first during which total nitrogen data was available to the Lake and Wetland Monitoring Program, thus making the determination of limiting nutrients possible.

Table 9 presents limiting factor determinations for the lakes surveyed during 1996. It should be kept in mind that these determinations reflect the time of sampling (which is chosen to reflect "average" conditions during the summer months to the extent possible) but may not apply to other times of the year. There is, however, always the chance that conditions during one survey will differ from conditions during past surveys, despite efforts to sample during times representative of "normal" conditions. If such conditions are suspected, they will be noted in Table 9.

As can be seen from the data in Table 9, phosphorus is the primary limiting factor for lakes surveyed during the summer of 1996. Twenty-six of the 43 lakes (60%) were primarily phosphorus limited. Four lakes (9%) were limited primarily by nitrogen. Five lakes (12%) were co-limited by nitrogen and phosphorus. Seventeen lakes had some indication of light limitation, but this limiting factor was only significant in eight lakes (19%).

Four additional metrics are included, as of this report, in determining the relative roles of light and nutrient limitation for lakes in Kansas. These metrics, and their description follow (Walker, 1986).

1) Non-Algal Turbidity = (1/SD)-(0.025*C),

where SD = Secchi depth in meters and C = chlorophyll-a in mg/m^3.

Non-algal turbidity values of <0.4^{-m} tend to indicate <u>very</u> low levels of suspended silt and/or clay, while values >1.0^{-m} indicate that inorganic particles are important in creating turbidity. Values between 0.4 and 1.0^{-m} describe a range where inorganic turbidity assumes greater importance as the value increases, but would not assume a significant role until values exceed 1.0^{-m}.

Table 9. Limiting factor determinations for the 43 surveyed lakes in 1996, including TN/TP ratios and other metrics. Factors are listed in descending order of importance (P = phosphorus, N = nitrogen, and L = light). Presence of the symbol "*" indicates that past data differed sufficiently from 1996 to warrant using it to modify the primary limiting factors.

Lake	TN/TP Ratio	Non-Algal Turbidity	Light In Mixed Layer	Light Partitioning	Algal TP Use	Limiting Factors
Atchison Co. Lake	10.5	9.82	2.81	0.72	0.04	N>P>=L
Augusta SF Lake*	7.7	2.91	3.415	5.13	0.11	N>P=L*
Barber Co. SFL	57.5	1.19	1.97	6.65	0.32	P
Bronson City Lake*	36.8	0.52	1.25	20.45	0.48	P*
Butler Co. SFL	4.7	0.79	0.92	21.15	0.32	N=P
Centralia Lake	18.2	1.09	3.25	18.13	0.56	P
Chanute SF Lake	18.8	<0.05	<0.05	45.48	0.71	P
Chase Co. SFL	38.0	0.41	1.42	10.17	0.38	P
Cheney Lake	3.4	1.96	8.80	0.80	0.01	L
Clinton Lake*	na	0.72	3.24	11.10	0.08	N=P*
Council Grove Lake	3.7	4.80	20.15	1.64	0.06	L
El Dorado Lake	14.9	2.14	11.40	1.58	0.07	L
Ford Co. Lake	6.0	0.65	0.76	29.60	0.26	P=N
Fort Scott City Lake	87.0	0.42	1.34	9.90	0.28	P
Harvey Co. West Lake	11.2	1.87	1.12	13.81	0.40	P>N
Harveyville Reservoir	18.0	1.30	1.53	3.68	0.35	P>L
Herington Reservoir	26.7	0.91	2.71	18.15	0.61	P
Hiawatha City Lake	28.9	2.95	6.60	4.61	0.15	P=L
Hillsdale Lake*	10.1	0.53	2.63	14.80	0.39	P*
John Redmond Lake	7.2	9.90	14.71	0.39	0.02	L
Lake Afton	11.9	0.38	0.92	29.33	0.65	P
Lake Anthony	7.0	2.54	0.73	19.65	0.35	P=N
Lake Miola	41.2	0.72	2.15	11.15	0.45	P
Lake Parsons	13.8	9.93	22.22	0.29	0.02	L
Lone Star Lake	129.5	0.57	1.83	17.20	1.72	P
Louisburg SFL	165.5	0.68	1.73	10.29	0.94	P
Marais des Cygnes WMA	2.2	2.40	0.14	20.82	0.22	N>=P

Table 9. Continued.

Lake	TN/TP Ratio	Non-Algal Turbidity	Light In Mixed Layer	Light Partitioning	Algal TP Use	Limiting Factors
Marion Lake	18.2	1.30	4.40	8.82	0.25	P>L
Melvern Lake	55.3	1.28	6.69	4.17	0.79	P=L
Miami Co. SFL	12.4	2.72	0.78	12.76	0.33	P
Milford Lake	4.0	0.85	4.79	6.05	0.05	N>L
Mission Lake	9.0	9.89	16.36	0.44	0.01	L
Neosho WMA	7.8	7.33	0.66	10.68	0.36	P>N
Perry Lake*	8.8	1.43	6.40	5.76	0.06	L=N*
Pleasanton Reservoir	34.4	0.77	1.86	15.32	0.43	P
Pomona Lake	13.1	4.94	25.82	0.50	0.03	L
Pony Creek Lake	47.7	0.46	1.57	29.04	1.61	P
Richmond City Lake	>12.0	0.55	1.77	9.17	0.66	P
Shawnee Co. SFL	47.8	0.96	3.07	5.58	0.41	P>>L
Shawnee Mission Lake	49.3	0.60	2.06	6.37	0.23	P
Sheridan Co. SFL	15.2	1.02	2.10	21.67	0.51	P
Tuttle Creek Lake	8.8	2.14	11.62	1.58	0.02	L
Wilson Co. SFL	36.5	0.53	2.02	16.72	0.38	P

* = Augusta SF Lake (recent storm may have influenced lake condition).
Bronson City Lake (no boat access, used previous mean Secchi data as the lake appeared similar to past surveys).
Clinton & Hillsdale Lakes (1996 nitrogen data suspect, relied on past data).
Perry Lake (lake unusually turbid).

Table 9. Continued.

Expected Lake Condition	TN/TP Ratio	Non-Algal Turbidity	Light In Mixed Layer	Light Partitioning	Algal TP Use
Phosphorus Limiting	>12				>0.4
Nitrogen Limiting	<7				<0.13
Light/Flushing Limited		>1.0	>6	<6	<0.13
High Algae-Nutrient Response		<0.4	<3	>16	>0.4
Low Algae-Nutrient Response		>1.0	>6	<6	<0.13
High Inorganic Turbidity		>1.0	>6	<6	
Low Inorganic Turbidity		<0.4	<3	>16	
High Light Availability			<3	>16	
Low Light Availability			>6	<6	

2) Light Availability in the Mixed Layer = Z_{mix}*Turbidity,

where Z_{mix} = depth of the mixed layer, in meters, and Turbidity = the previously mentioned Non-Algal Turbidity.

Values below 3 indicate abundant light, within the mixed zone of the lake, and a high algal response to nutrients. Values Above 6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Turbidity = Chl-a*Secchi Disk Depth,

where Chl-a = algal chlorophyll-a in mg/m^3 and Secchi depth in meters.

Values less than 6 indicate inorganic turbidity dominates light extinction in the water column and a poor algal-nutrient response. Values above 16 indicate the opposite.

4) Algal Use of Phosphorus Supply = Chl-a/TP,

where Chl-a = algal chlorophyll-a in mg/m^3 and TP = total phosphorus in mg/m^3.

Values less than 0.13 indicate a low algal response to phosphorus, indicating that nitrogen or light limitation may be important. Values above 0.4 indicate the opposite, while the range in-between suggests various levels of moderate algae-phosphorus response.

Surface Water Exceedences of State Water Quality Criteria

All numeric and narrative water quality criteria referred to in this section are taken from Chapter 28 of the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA 1972, 1976; KDHE, 1994). Copies of these standards may be obtained from the Bureau of Water, KDHE, Building 283, Forbes Field, Topeka, Kansas 66620.

Tables 11, 12 and 13 present documented exceedences of state surface water quality criteria during the 1996 sampling season. These data were generated by comparison of a computer data retrieval, for 1996 Lake and Wetland Monitoring Program ambient data, to the state surface water quality standards. Only those samples collected at a depth above 3.0 meters were used to document standards violations, as a majority of those samples below 3.0 meters are from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having a greater number of pollutants present in measurable quantities, do not necessarily pose a significant water quality problem for the lake as a whole.

Eutrophication criteria, in the Kansas surface water quality standards are narrative rather than numeric. This is partially due to the fact that the trophic status of any lake reflects a number of site-specific and regional environmental characteristics, combined with pollutant inputs from the watershed. However, lake trophic state does exert a documented impact on various lake uses. Based on numerous studies, that have been combined into other documents (EPA, 1990; NALMS, 1992), the scheme on the following page (Table 10) has been developed over the past eight years to define how lake trophic status impacts on the various designated uses of Kansas lakes. These trophic state/use support combinations are joined with the site-specific lake trophic state designations to determine use support levels at specific locations.

With respect to the aquatic life support use; atrazine, eutrophication, and low dissolved oxygen (within the upper 3.0 meters depth) comprise the major water quality concerns documented during 1996 (Table 11). Thirteen lakes exhibited trophic states high enough to impair normal uses, including long and short-term aquatic life support. Nineteen lakes exhibited atrazine herbicide levels that exceeded the chronic aquatic life support criterion in effect at the time of sampling. Eleven lakes had dissolved oxygen concentrations below the minimum water quality criterion.

Eutrophication exceedences are primarily due to excessive nutrient inputs from the watersheds that drain to these lakes. Dissolved oxygen exceedences may be due to trophic status, in part, but were also observed in lakes without excessive eutrophication. In these cases, the exceedence results from conditions that led to shallow stratification. Atrazine exceedences result from agricultural nonpoint source runoff.

As shown in Table 12, there were 27 exceedences of drinking water supply criteria during 1996. The majority of these were for eutrophication (20) and atrazine (6). Examining just those lakes that <u>currently</u> serve as water supplies, exceedences are reduced to less than half that number, although the same parameters still cause the majority of the documented exceedences. Irrigation use was impaired in 14 lakes, mostly due to high lake trophic state, but none of these lakes currently hosts the irrigation use. Likewise, livestock watering use was impaired at 14 lakes, but none currently host the livestock water use. Twenty lakes had high enough trophic status to impair contact recreation (Table 13). Nine of these lakes actually have swimming beaches and host the full range of contact recreational activities. High trophic state impaired the non-contact recreation uses of 13 lakes during 1996.

Table 10. Lake use support determination based on lake trophic state.

Use	Trophic State Code A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life	X	F	F	F	P	P	N	N
Drinking Water Supply	X	F	F	P	P	N	N	N
Contact Recreation	X	F	F	P	P	N	N	N
Non-Contact Recreation	X	F	F	F	P	P	N	N
Livestock Water Supply	X	F	F	F	P	P	N	N
Irrigation	X	F	F	F	P	P	N	N
Groundwater Recharge	not generally applicable							
Food Procurement	applicable, but not directly							

BG = bluegreen algae are dominant (50%+ as cell count and/or 33%+ as biovolume)

F = full support of the use
P = partial support of the use
N = use is not adequately supported
X = use support assessed based on nutrient load rather than algal biomass

A = argillotrophic (high turbidity limits algae production)
M = mesotrophic (includes the class O/M, oligo-mesotrophic), TSI = zero-to-49.9
SE = slightly eutrophic, TSI = 50-to-54.9
E = fully eutrophic, TSI = 55-to-59.9
VE = very eutrophic, TSI = 60-to-63.9
H = hypereutrophic, TSI = 64+

TSI = 64 = chlorophyll-a concentration of 30 ppb
TSI = 70 = chlorophyll-a concentration of 56 ppb

Table 11. Chemical parameters exceeding chronic and acute aquatic life support criteria in lakes surveyed during 1996. Chemical symbols are from the Periodic Table of the Elements. Atz = atrazine. Aquatic life support = ALS, dissolved oxygen = DO, and EN = eutrophication and high nutrient load. In 1998, the chronic criterion for atrazine was changed to 3 ppb. Those lakes that showed an exceedence in 1996, but would not at present, are indicated by parentheses.

	Chronic ALS								Acute ALS
Lake	Hg	Se	Cu	Zn	pH	Atz	DO	EN	EN
Atchison Co. Lake						(x)			
Augusta S.F. Lake							x		
Barber Co. SFL							x		
Bronson City Lake								x	
Butler Co. SFL								x	x
Centralia City Lake						x		x	x
Chanute S.F. Lake					x	(x)	x	x	x
Chase Co. SFL	x								
Clinton Lake						(x)			
Council Grove Lake		x							
Ford Co. Lake					x		x	x	x
Harvey Co. West Lake								x	x
Herington Reservoir						x	x	x	x
Hiawatha City Lake						x			
Hillsdale Lake						(x)			
John Redmond Lake						x			
Lake Afton								x	x
Lake Anthony					x			x	x
Lake Miola							x		
Lake Parsons						(x)			
Lone Star Lake						(x)	x		
Louisburg SFL						(x)			
Marais des Cyg. WMA								x	x
Marion Lake						(x)			
Melvern Lake						(x)			
Miami Co. SFL					x			x	x
Milford Lake						(x)			
Mission Lake			x						
Neosho WMA				x				x	x
Perry Lake						(x)			
Pleasanton Reservoir							x		
Pomona Lake						x			
Pony Creek Lake						(x)		x	x
Shawnee Mission Lake							x		
Sheridan Co. SFL							x	x	x
Tuttle Creek Lake						(x)			
Wilson Co. SFL						x	x		

Table 12. Exceedences of human use criteria and/or EPA guidelines within the surface waters of the lakes surveyed during 1996. Symbols are taken from the Periodic Table of the Elements. Atz = atrazine, SO4 = sulphate, and EN = eutrophication and high nutrient load. The human health use category refers to ambient water quality considered protective for human consumption of aquatic life. Only lakes with documented exceedences are included within the table. An "x" indicates that the exceedence occurred for a use presently existing, or likely in the foreseeable future, at the given lake. An "*" indicates that the exceedence occurred where the indicated use has not yet been determined.

	Water Supply			Irrigation	Human Health		Livestock Water
Lake	Atz	EN	SO4	EN	Hg	FC	EN
Augusta S.F. Lake						x@	
Barber Co. SFL			*				
Bronson City Lake		x		*			*
Butler Co. SFL		*		*			*
Centralia City Lake	*	*		*			*
Chanute S.F. Lake		*		*			*
Chase Co. SFL					x		
Ford Co. Lake		*		*			*
Harvey Co. West Lk.		*		*			*
Herington Reservoir	x	x		*			*
Hiawatha City Lake	x	x					
Hillsdale Lake		x					
John Redmond Lake	x						
Lake Afton		*		*			*
Lake Anthony		*		*			*
Lone Star Lake		*					
Marais des Cyg. WMA		*		*			*
Marion Lake		x					
Miami Co. SFL		*		*			*

@ = A runoff event, which occurred the day before the survey, is believed to have influenced the bacteria data from Augusta Santa Fe Lake.

Table 12 continued. Exceedences of human use criteria and/or EPA guidelines within the surface waters of the lakes surveyed during 1996. Symbols are taken from the Periodic Table of the Elements. Atz = atrazine, SO4 = sulphate, and EN = eutrophication and high nutrient load. The human health use category refers to ambient water quality considered protective for human consumption of aquatic life. Only lakes with documented exceedences are included within the table. An "x" indicates that the exceedence occurred for a use presently existing, or likely in the foreseeable future, at the given lake. An "*" indicates that the exceedence occurred where the indicated use has not yet been determined.

	Water Supply			Irrigation	Human Health		Livestock Water
Lake	Atz	EN	SO4	EN	Hg	FC	EN
Neosho WMA		*		*			*
Pleasanton Res.		x					
Pomona Lake	x						
Pony Creek Lake		x		*			*
Sheridan Co. SFL		*		*			*
Wilson Co. SFL	*	*					

Table 13. Exceedences of applicable numeric and narrative water quality criteria for the lakes sampled in 1996, as relates to recreational uses. Contact recreation refers to recreational activities that make accidental ingestion of water highly probable. Non-contact recreational activities do not have a high likelihood of accidently ingesting lake water. "FC" = fecal coliform bacteria and "EN" = eutrophication and nutrient load. An "x" indicates that the exceedence occurred for a use presently existing, or likely in the foreseeable future, at the given lake. An "*" indicates that the exceedence occurred where the indicated use does not presently exist. Only those lakes with exceedences are included in the table.

Lake	Contact Recreation FC	Contact Recreation EN	Non-Contact Recreation EN
Augusta Santa Fe Lake @	x		
Bronson City Lake		*	
Butler Co. SFL		*	x
Centralia City Lake		x	x
Chanute Santa Fe Lake		*	x
Ford Co. Lake		*	x
Harvey Co. West Lake		x	x
Herington Reservoir		*	x
Hiawatha City Lake		*	
Hillsdale Lake		x	
Lake Afton		x	x
Lake Anthony		x	x
Lone Star Lake		x	
Marais des Cygnes WMA		*	x
Marion Lake		x	
Miami Co. SFL		*	x
Neosho WMA		*	x
Pleasanton Reservoir		x	
Pony Creek Lake		*	x
Sheridan Co. SFL		*	x
Wilson Co. SFL		*	

@ = Augusta Santa Fe Lake experienced a runoff event the day prior to being surveyed. It is unlikely that high bacterial counts are normal for either the summer or year as a whole.

The "human health" use refers to water quality conditions that are felt to be protective of human consumption of indigenous aquatic life (Table 12). One lake exceeded the applicable criterion for mercury during 1996. An additional lake is listed here due to high fecal coliform bacteria counts (Table 13).

Pesticides in Kansas Lakes, 1996

Thirty lakes had detectable levels of pesticides within the main body of the lake during 1996. Table 14 lists these lakes and the pesticides that were detected, along with the level detected and analytical quantification limit. Six different pesticides, and one pesticide degradation by-product, were detected in total.

Atrazine continues to be the most often detected pesticide in Kansas (KDHE, 1991). Atrazine was identified in all 30 lakes with detectable levels of pesticides. Eighteen lakes had detections of Dual (metolachlor), 14 lakes had detections of alachlor, and 16 lakes had detections of deethylatrazine during 1996. In addition, there was a single detection for simazine, two lakes had detections of cyanazine (Bladex), and two lakes had detections of acetochlor (Harness or Surpass). The 1996 sampling year represents the first time that the herbicide acetochlor has been detected in Kansas lakes.

In all cases, the detection of these pesticides indicates impacts from agricultural nonpoint source pollution, although the simazine detection in Lake Miola may be indicative of urban weed control, at least to some degree. The sites of most concern during 1996 were Atchison County Lake, Centralia Lake, Council Grove Lake, Herington Reservoir, Hiawatha City Lake, Hillsdale Lake, John Redmond Lake, Lake Miola, Mission Lake, Perry Lake, Pomona Lake, Pony Creek Lake, and Tuttle Creek Lake, based on the number of pesticides detected in each. Lakes of most concern, based on the absolute concentrations seen in 1996, include Atchison County Lake, Centralia Lake, Herington Reservoir, Hiawatha City Lake, John Redmond Lake, Pomona Lake, Tuttle Creek Lake, and Wilson County SFL.

Discussion of Nonpoint Sources of Pollution for Selected Lakes

Certain lakes and wetlands were chosen for further discussion, based on the number and type of surface water quality standards exceedences that were observed. A waterbody was chosen if 1) three, or more, parameters exceeded chronic aquatic life support criteria, 2) more than one parameter exceeded acute aquatic life support criteria, or 3) more than one parameter exceeded irrigation, water supply, livestock watering, or human health criteria.

Table 14. Pesticides detected during 1996 in Kansas lakes. All values are in ug/L. Analytical quantification limits are as follows for the seven detected pesticides and degradation by-products: atrazine (Atz) = 0.3 ug/L, metolachlor (Dual) = 0.25 ug/L, alachlor (Ala) = 0.1 ug/L, simazine (Sim) = 0.3 ug/L, deethylatrazine (deatz) = 0.3 ug/L, cyanazine (Cyan) = 0.5 ug/L, and acetochlor (Acet) = 0.1 ug/L .

Lake	Pesticide						
	Atz	Deatz	Dual	Ala	Sim	Cyan	Acet
Atchison Co. Lake	1.50	2.40	4.00	0.22		1.60	
Augusta SF Lake	0.81						
Bronson City Lake	0.92						
Centralia Lake	4.00	1.70	3.20	1.20			
Chanute SF Lake	2.60	0.32					
Clinton Lake	2.10	0.30	0.43				
Council Grove Lake	0.95	0.30	0.49	0.29			
El Dorado Lake	0.37						
Ford Co. Lake	0.55						
Herington Reservoir	6.40	1.40	1.60	1.00			
Hiawatha City Lake	9.20	4.40	14.00	0.62			
Hillsdale Lake	2.60		0.28	0.14			
John Redmond Lake	4.50		1.40	0.36			
Lake Afton	0.48						
Lake Miola	0.84	0.35	0.38		0.84		
Lake Parsons	2.10			0.32			
Lone Star Lake	2.20		0.71				
Louisburg SFL	1.20			0.10			
Marion Lake	1.60		0.54				
Melvern Lake	1.80	0.30					
Milford Lake	2.30	0.55	1.50				
Mission Lake	0.54	1.30	1.10	1.60			0.19
Perry Lake	1.40	0.63	1.30	0.32			

Table 14 continued.

Lake	Pesticide						
	Atz	Deatz	Dual	Ala	Sim	Cyan	Acet
Pleasanton Reservoir	0.43						
Pomona Lake	4.40	0.51	1.50	0.38			
Pony Creek Lake	1.30	0.34	0.37	0.11		1.90	
Richmond City Lake	0.81						
Shawnee Mission Lake	0.33						
Tuttle Creek Lake	2.00	0.59	3.00	0.88			0.23
Wilson Co. SFL	3.80	0.31	1.40				

Based on the three selection criteria in the previous paragraph, six lakes and wetlands were chosen for further discussion. Each selected lake or wetland will be briefly examined to identify the possible causes and sources of its documented water quality problems.

Centralia City Lake

This 400+ acre lake drains a large area of cultivated land (80% of total drainage is in rowcrops). While the main body of the lake is relatively deep, both arms are relatively shallow which allows for some degree of wind re-suspension of sediments. Given that this lake is part of the Governor's Water Quality Initiative in the Kansas/Lower Republican River Basin, it will receive a full macrophyte survey during 1997.

Chanute Santa Fe Lake

This lake has been the location of an EPA Clean Lakes Program project in the past. It receives drainage from both urban (15% of drainage) and cultivated (40% of drainage) land. Much of the lake is also shallow, although wind induced turbidity does not appear to be a common feature of the system. During 1996, shallow stratification and intense algal productivity created high pH in the surface water combined with low dissolved oxygen levels within the upper 3.0 meters of the lake.

Ford County Lake

This lake has been the site of an EPA Clean Lakes Program restoration project. Water quality problems during 1996 revolved around intense algal productivity combined with strong, shallow, stratification. Past problems centered around sedimentation. While the lake has been dredged, and some effort has been made to prevent eroded silt from reaching the main body of the lake, there is a high potential for sedimentation to become a problem again.

Herington Reservoir

This lake has also been the site of an EPA Clean Lakes Program project. Water quality problems at this lake center around eutrophication and herbicide runoff from a large, highly cultivated, watershed (58% of total drainage is cropland). Efforts to control nutrient and herbicide loads from nonpoint sources continue at a local level.

Hiawatha City Lake

This smaller lake receives considerable herbicide load in the runoff from its relatively small, cultivated watershed (85% of watershed is in rowcrops). Eutrophication is limited due to turbid conditions from suspended silt. Sedimentation is suspected of being a serious problem.

Wilson County SFL

This lake normally experiences "good" water quality, with the exception of persistent pesticide detections (atrazine) which result from nonpoint sources (39% of watershed is in rowcrops). The lake is included in this discussion due to relatively shallow stratification, low dissolved oxygen within the upper 3.0 meters, and slight impacts from eutrophication, combined with the previously mentioned elevated pesticide levels.

Taste and Odor/Algae Bloom Investigations and Other Special Investigations in 1996

During the period of November 1, 1995 to October 31, 1996, eleven investigations were undertaken within the auspices of the Taste and Odor/Algae Bloom Program. Each will be discussed individually within the remainder of this section. Two of the investigations were related to fishkills, seven dealt partially or wholly with visual aesthetic complaints, two dealt with odor complaints, one dealt with taste and odor complaints in finished drinking water, and one dealt with livestock refusing to drink from a pond.

The Kanopolis Lake difficulties, which are discussed in the 1995 Lake and Wetland Monitoring Program Report, continued into 1996. These difficulties still revolve around the poor condition of fish caught within the lake. Additional water quality testing was conducted during June, 1996, to attempt to shed some light on the continuing problem. Sampling appears to indicate that biochemical oxygen demand has "spiked" within the lake from time-to-time, and may have some relationship to lake level changes at specific times of the year. Whether this would be directly connected to the problems with the fishery is unknown. The problem continues to be monitored. Algae samples related to these investigations indicate no involvement of algae blooms with fishery problems.

On November 17, 1995, algae samples were examined in relation to a complaint of "foam" on the Wet Walnut River downstream of where the inflow canal to Cheyenne Bottoms diverges. The algae community was moderate in size (about 13,500 cells/mL), and mostly composed of small flagellates from both the Chlorophyta (green algae) and Euglenophyta (euglenoid algae). Euglenoids were responsible for the majority of algal biomass. It was indicated that the foam and the euglenoid community may both have been due to upstream organic enrichment, but the algae were not the direct cause of the foam.

On November 29, 1995, algae samples for Chisholm Creek, located in Wichita, Kansas, were submitted by the KDHE South-Central District Office. The creek was reported as having milky-white coloration, a hydrogen sulfide odor, and the general appearance of severe organic enrichment. The samples yielded very little algae, but did contain some protozoan and fungal species. It was indicated that abundant leaf litter, combined with an extended period of low runoff, likely was the cause of the problem. However, as there had been past instances of sewage or septic system leachate discharging to small streams in Wichita, it was recommended that additional sampling be undertaken to further document the source of the problem.

On December 5, 1995, algae samples were sent from Indian Creek, at Lindsborg, Kansas, by KDHE North-Central District Office staff. The initial complaint had been of a red coloration in the stream. Examination of the samples revealed a community of an unknown organism, assumed to be a protozoan, with a distinctive red coloration. The organism did not correspond to any algae staff were able to identify. Given that the stream was, and had been, stagnant for an extended period, the coloration was likely the result of microbiological community changes brought about by the lack of flow.

On February 22, 1996, algae samples from Eight Mile Creek, below the Rosehill, Kansas, wastewater treatment plant, were submitted by KDHE South-Central District Office staff. A citizen complaint had indicated objectionable odors were emanating from the creek. The samples indicated that there was a great abundance of the filamentous green algae <u>Spirogyra</u> sp. within the creek. Such filamentous algae abundance in streams immediately below wastewater treatment facilities is common, although <u>Cladophora</u> spp. have been identified more commonly within the literature. It was indicated that downstream eutrophication could be the cause of the odors, as algal filaments died off and contributed to the organic load of the immediate stream reach.

On April 19, 1996, KDHE South-Central District Office staff submitted algae samples from a private pond in Butler County that is used for livestock watering. The pond owner indicated that the pond had been shallow for some time, due to low rainfall, but the cattle had only recently begun to refuse drinking the water. The algae samples contained an abundant community of euglenoid, diatom, and dinoflagellate algae. The pond also contained an abundance of the filamentous chrysophyte (golden) algae <u>Vaucheria</u> sp. It was offered that, as the pond shrunk in volume, it had concentrated various constituents in the water column that may have finally made the water unpalatable to the cattle. It was also possible that some of the diatom or dinoflagellate algae produced metabolic by-products that made the water unpalatable. In either case, the only feasible solution would have been to find an alternate water source until rainfall returned the pond to normal water levels.

On August 13, 1996, KDHE North-Central District Office staff investigated a complaint at a private watershed dam. The complaint involved an odd blue-green coloration along the shoreline and dam, and objectionable odors from the pond. Blue-green algae were thought to be the immediate cause of the problems. The complainant also implicated a feedlot operation, located just upstream, as the likely source of the problem. The situation with this particular pond, and this particular upstream feedlot, is a repetition of complaints from the past. Algae samples revealed only a very small community of chlorophyte, euglenoid, blue-green, and cryptophyte algae. The water sample also contained an abundance of microscopic organic debris. The most remarkable thing about the samples was the lack of a larger community, given the time of year, the level of enrichment, and the small pond size/depth. The upstream feedlot demonstrated no observable discharge, past or current. While the coloration may have been due to blue-green algae growing on the soil, no shoreline soil samples were submitted. The odors coming from the pond appeared to result from organic decomposition, given the amount of debris evident in the water samples.

On August 23, 1996, KDHE South-Central District Office staff investigated a complaint at "Hidden Lakes," which is a group of small ponds located in a residential area of Wichita, Kansas. The complaint was that one, or more, ponds had developed a floating scum that was described as "red-orange-brown-green." Algae samples were composed of euglenoid and blue-green algae, with the total population at about 36,000 cells/mL. Euglenoid algae comprised over half of the cell count and over 95% of the total biomass. The colored scum on the pond was due to a surface bloom of euglenoid algae.

On September 5, 1996, KDHE Southeastern District Office staff investigated a pond located in a residential development east of Chanute, Kansas. District Office staff indicated they suspected septic system failures were subjecting the pond to high levels of nutrient loading. Fish in the pond were observed coming to the surface in numbers and gulping air. The algae samples submitted revealed the largest density of algae this investigator has ever examined. The pond community was composed entirely of the blue-green algae Aphanizomenon flos-aqua, with the cell count reaching an incredible 12,600,000 cells/mL. There was sufficient sample to conduct chlorophyll-a analysis on, with the result being another record. Chlorophyll-a, which is a common and accepted measure for algal biomass, was recorded at 8,900 ug/L, which is roughly two orders of magnitude larger than has been recorded from any other waterbody in the state. It was indicated to District Office staff that for the pond to maintain a bloom of that magnitude it would necessitate significant nutrient inputs. As to the potential for a fishkill, it was indicated that the likelihood was high, either from night-time loss of dissolved oxygen, algal toxins, or from direct gill clogging.

On September 26, 1996, KDHE Northeast District Office staff submitted algae samples from Pomona Lake. Complaints of taste/odor problems in drinking water from customers of Osage County Rural Water District #3 had been received, as well as complaints of skin rashes from one mobile home park area. Algae samples indicated a moderate algae community within the lake, and a larger algae community from the immediate intake area. Both algae communities were dominated by the blue-green algae Anabaena spp. and the filamentous diatom Melosira sp. The literature indicated that either species could have produced the identified taste/odor problems (earthy/musty odor). The skin rashes from a localized area served by the rural water district were deemed unrelated to algae or the water. District Office staff indicated that they observed brush burning taking place at the mobile home park about the time the skin rashes were reported. It was suggested that inadvertent burning of poison ivy could have been the cause of such rashes.

On September 27, 1996, an algae sample was submitted from a private citizen who owns a home at, and acts as caretaker for, the Seven Hills Lake in Kansas City, Kansas. This lake appeared to have developed a red coloration, which a passing crew from a local property management service noticed. The crew told residents around the lake that the problem was "red algae," and it would "kill" the lake unless they had someone treat it. Understandably, this caused great concern from the residents, who were not sure what the problem might really be. The concern of the management crew that contacted the residents was also (apparently) considered suspect, as the crew indicated they knew how to cure the problem for a fee. KDHE staff agreed to examine samples from the lake to provide residents with enough information on which to develop a plan of action.

Samples of the water from Seven Hills Lake contained a moderate abundance of red filaments that matched no algae in agency references. The material was finally identified as a previously unknown (to KDHE in any event) filamentous aquatic fungus. Both the abundance of fungi, and the coloration (at odds with most fungal material), were extremely unusual for a lake environment in Kansas. It was suggested that the presence of such unusual conditions indicated an "imbalance" within Seven Hills Lake, which may have resulted from pollutant influxes, hydrologic changes, and/or management practices to control other components in the biotic community. Materials on basic lake ecology were provided to the concerned citizen who initially contacted the agency, along with an offer to provide additional advice or technical assistance in the future.

CONCLUSIONS

The following conclusions are offered, based upon the lake monitoring data obtained during 1996.

1. Trophic state conditions suggested that most lakes surveyed in 1996 (about 60%) were stable, in terms of past trophic state compared to current condition. Another 23% indicated a degradation of lake quality over time, as evidenced by increases in trophic status. The remaining 17% displayed some improvement in trophic status compared to their last survey. This is reasonably consistent with past years of survey data, despite the fact that 1) a trophic state classification (argillotrophic) was substituted for lakes with chronic turbidity problems and 2) additional lakes with known water quality problems were included as part of the Governor's Water Quality Initiative.

2. Exceedences of surface water quality criteria revolved primarily around three parameter groups. First, eutrophication and high nutrient loads. Second, pesticide levels (primarily atrazine). Third, in-lake processes (high pH due to algal productivity and low dissolved oxygen due to shallow thermoclines). It is likely that the low dissolved oxygen problems can be attributed to natural stratification, or linked to general nonpoint source pollution (i.e., eroded soil and nutrients). High pH and eutrophication may have a small level of natural background influence, but are primarily due to excessive nutrient loads from urban and agricultural watersheds. Pesticide problems are almost entirely due to agricultural practices.

3. Thirty of the 43 surveyed lakes (70% of the total) had detectable concentrations of agricultural pesticides during the summer of 1996. Atrazine was the most commonly encountered pesticide (70% of lakes). Roughly 44% of lakes surveyed in 1996 exceeded the chronic aquatic life support criterion for atrazine that was in effect during the 1996 sampling season. An additional 14% exceeded the drinking water supply criterion for atrazine. While no criteria exist (or were not exceeded where they did exist) for metolachlor (Dual), alachlor, or deethylatrazine, detections of these three pesticides were frequent and of concern to water quality. The 1996 season was the first time that the herbicide acetochlor was detected in Kansas lakes. This herbicide is being marketed as a replacement for atrazine, and will likely be detected in greater numbers of Kansas waterbodies in the future.

REFERENCES

Brooks, E. B. and L. A. Hauser, Aquatic Vascular Plants of Kansas 1: Submersed and Floating Leaved Plants. Kansas Biological Survey, Technical Publication #7. 1981.

Carlson, R. E., A Trophic State Index for Lakes. Limnology and Oceanography, 22(2), 1977, p. 361.

EPA, Ecological Research Series, Water Quality Criteria 1972. National Academy of Sciences/National Academy of Engineering. 1972.

EPA, Quality Criteria for Water. United States Environmental Protection Agency, Washington, D.C. 1976.

EPA, The Lake and Reservoir Restoration Guidance Manual, Second Edition. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA-440/4-90-006. 1990.

Haynes, R. C., An Introduction to the Blue-Green Algae with an Emphasis on Nuisance Species. North American Lake Management Society, Washington, D.C. 1988.

Henning, M. H. and K. H. Reckhow, Using Eutromod. Duke University School of Forestry and Environmental Studies. 1990.

Hutchinson, G. E., A Treatise on Limnology, Volume 1: Geography, Physics, and Chemistry. John Wiley & Sons, Inc., New York. 1957.

Kansas Department of Health and Environment, Atrazine in Kansas, Second Edition. 1991.

KDHE, Division of Environment Quality Management Plan, Part III: Lake and Wetland Water Quality Monitoring Program Quality Assurance Management Plan, 1995.

KDHE, Kansas Surface Water Quality Standards. 1994.

Mallevialle, J. and I.H. Suffet, Identification and Treatment of Tastes and Odors in Drinking Water. AWWA Research Foundation and the Lyonnaise des Eaux. 1987.

Naumann, E. The Scope and Chief Problems of Regional Limnology. Int. Revue ges. Hydrobiol, Vol. 21. 1929.

North American Lake Management Society (NALMS), Developing Eutrophication Standards for Lakes and Reservoirs. NALMS Lake Standards Subcommittee, Alachua, Florida. 1992.

North American Lake Management Society (NALMS), Lake and Reservoir Management, Vol. 9, No. 2, October 1994, pp. 70-71, 116.

Palmer, C. M., Algae In Water Supplies: An Illustrated Manual on the Identification, Significance, and Control of Algae in Water Supplies. U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 657. 1959.

Reckhow, K. H., M. N. Beauliac, and J. T. Simpson, Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. US EPA Office of Water Regulations and Standards, 440/5-80-011. 1980.

Reckhow, K. H., S. W. Coffey, and C. Stow, Technical Release: Managing the Trophic State of Water Bodies. US Soil Conservation Service. 1990.

Walker, W. W., Jr. Empirical Methods for Predicting Eutrophication in Impoundments; Report 4, Phase III: Applications Manual. Technical Report E-81-9, United States Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 1986.

Wetzel, R. G., Limnology, Second Edition. Saunders College Publishing, New York. 1983.

LAKE DATA AVAILABILITY

Lake data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. Water quality data may be requested by writing to the Bureau of Environmental Field Services, KDHE, Building 283, Forbes Field, Topeka, Kansas 66620-0001. All data referenced within this report are also accessible on STORET.

Appendix

Relationships Between Algal Numbers, Chlorophyll-a, and Biovolume

Chlorophyll-a is almost universally used as a surrogate measure of algal biomass (Carlson, 1977; Wetzel, 1983; EPA, 1990). However, each species of algae will possess certain specific features that may add "noise" to the relationship between the amount of chlorophyll-a pigment and the numbers of algal cells. That is, no two species of algae have the exact same size or shape. Calculation of algal biovolume can take some of these size and shape differences into account, although not all. In addition, many species of algae can, for brief periods of time, produce excess amounts of "light harvesting pigments" in order to take full advantage of specific environmental conditions, adding further "noise" to these relationships.

Data for algal cell counts, with corresponding chlorophyll-a data, were available for the sampling years 1991-to-1996. During 1996, algal biovolume was also calculated for comparison with the other two parameters. These data were used to produce several mathematical relationships between these three parameters, which may have some value in management of Kansas lakes. For instance, chlorophyll-a analysis normally takes a minimum of one or two months between collection and analysis due to resource constraints and time needed for freeze-drying the sample. If an estimate of algal biomass is needed more rapidly, an investigator must turn to cell/biovolume counts. However, these numbers will not be as "powerful," when presented to the citizenry at large, as are the more universally used chlorophyll-a values. If an investigator had access to a simple mathematical formula to estimate chlorophyll-a from one, or both, of the other parameters, it would have a good deal of value for making short-term lake management decisions.

The data from 1991-to-1996 were examined to produce a set of such simple relationships. The data were initially analyzed using non-parametric statistical methods and graphical analysis. Best-fit linear equations were then calculated, along with some measure of the level of uncertainty around predicted values. The data were also divided among those lakes that were dominated by blue-green algae at the time of sample collection, and those that were not. As blue-green algae are often the cause of severe blooms, and are among the more important nuisance algae, the distinction seemed a valuable one to investigate. Blue-green algae were considered to dominate the algal community if they comprised 50%+ of the total cell count and/or 33%+ of the calculated total biovolume.

Chlorophyll-a Versus Algal Cell Counts

Data from the six year period of 1991-to-1996 were available for this analysis. Table A1 lists the non-parametric correlation coefficients, and the level of significance, for the period of record as well as for 1996 data alone. A positive and highly significant relationship existed between algal cell count and chlorophyll-a. The best relationship was achieved by performing a square root transformation of the cell counts before analysis. While all groups demonstrated a significant correlation, lakes with blue-green algae communities tended to have a stronger cell count-to-chlorophyll-a relationship.

Table A1. Non-parametric Spearman rank-order correlation coefficients and related information for a comparison of algal cell counts and chlorophyll-a.

Time Period and Algae Type	Correlation Coefficient (r)	Degrees of Freedom	Level of Significance
1991-1996 All Data	+0.82	192	P<0.001
1991-1996 Non Blue-Green Lakes	+0.61	126	P<0.001
1991-1996 Blue-Green Lakes	+0.81	64	P<0.001
1996 Only All Data	+0.81	50	P<0.001
1996 Only Non Blue-Green Lakes	+0.72	30	P<0.001
1996 Only Blue-Green Lakes	+0.75	18	P<0.001

Using the same two data sets, "best fit" linear equations were developed for the relationship between cell count and chlorophyll-a. These formulas are listed below. As can be seen, the two data sets are similar, but the larger data set produces lower variation around the predicted value, making Formulas 1, 3, and 5 the equations of choice for use. The example cell count chosen for use in this report (10,000 cells/mL) is fairly widely used by both the Army Corps of Engineers and the EPA as a value describing the beginning of bloom conditions within lakes and reservoirs. As can be seen from Formula 1, 10,000 cells/mL should describe a lake just entering the "fully eutrophic" classification (mean chlorophyll-a between 12.1-to-20.0 ppb). Such lakes generally have full support for uses such as non-contact recreation, livestock watering, irrigation, and aquatic life support, but will only be able to partially support the more eutrophication sensitive uses of contact recreation and drinking water supply.

Formula 1: Derived from the 1991-to-1996 data set.

Chlorophyll-a (ppb) = 0.143(@sqrt(Cell Count (no./mL))) - 0.51

For an algal cell count of 10,000 cells/mL, the ± 95% confidence interval is 10.3-to-17.3 ppb of chlorophyll-a, with a "best estimate" of 13.8 ppb.

Formula 2: Derived from the 1996 data set.

Chlorophyll-a (ppb) = 0.139(@sqrt(Cell Count (no./mL))) + 1.51

For an algal cell count of 10,000 cells/mL, the ± 95% confidence interval is 9.4-to-21.4 ppb of chlorophyll-a, with a "best estimate" of 15.4 ppb.

Formula 3: Derived from the 1991-to-1996 data set, using lakes without any significant blue-green algae communities.

Chlorophyll-a (ppb) = 0.130(@sqrt(Cell Count (no./mL))) + 1.08

For an algal cell count of 10,000 cells/mL, the ± 95% confidence interval is 9.6-to-18.5 ppb of chlorophyll-a, with a "best estimate" of 14.1 ppb.

Formula 4: Derived from 1996 data set, using lakes without any significant blue-green algae communities.

Chlorophyll-a (ppb) = 0.132(@sqrt(Cell Count (no./mL))) + 1.50

For an algal cell count of 10,000 cells/mL, the ± 95% confidence interval is 6.4-to-23.0 ppb of chlorophyll-a, with a "best estimate" of 14.7 ppb.

Formula 5: Derived from 1991-to-1996 data set, using lakes supporting significant blue-green algae communities.

Chlorophyll-a (ppb) = 0.155(@sqrt(Cell Count (no./mL))) - 4.07

For an algal cell count of 10,000 cells/mL, the ± 95% confidence interval is 2.1-to-20.8 ppb of chlorophyll-a, with a "best estimate" of 11.5 ppb.

Formula 6: Derived from 1996 data set, using lakes supporting significant blue-green algae communities.

Chlorophyll-a (ppb) = 0.133(@sqrt(Cell Count (no./mL))) + 3.59

For an algal cell count of 10,000 cells/mL, the ± 95% confidence interval is 1.0-to-32.8 ppb of chlorophyll-a, with a "best estimate" of 16.9 ppb.

Chlorophyll-a Versus Algal Biovolume

Data from the 1996 sampling year were available for this analysis. Table A2 lists the non-parametric correlation coefficients and the level of significance. A positive and highly significant relationship existed between algal biovolume and chlorophyll-a. In fact, it would appear that biovolume correlates much better with chlorophyll-a than does cell count. As biovolume incorporates much of the variability in cell shape and size, which cell counts alone can't include, the superiority of using biovolumes should not be a great surprise. As was the case in the previous section, there tends to be a slightly stronger relationship between biovolume and chlorophyll-a for lakes with significant blue-green algae.

Table A2. Non-parametric Spearman rank-order correlation coefficients and related information for a comparison of algal biovolume calculations and chlorophyll-a.

Time Period And Algae Type	Correlation Coefficient (r)	Degrees of Freedom	Level of Significance
1996 Only All Data	+0.91	50	P<0.001
1996 Only Non Blue-Green Lakes	+0.77	30	P<0.001
1996 Only Blue-Green Lakes	+0.89	18	P<0.001

Three equations were derived for the algal biovolume versus chlorophyll-a relationship. These equations follow.

Formula 7: Derived from 1996 data set.

Chlorophyll-a (ppb) = 1.901(Biovolume (mm^3/L)) + 3.87

For an algal biovolume of 6.160 ppm (mm^3/L), the ± 95% confidence interval is 11.0-to-20.1 ppb of chlorophyll-a, with a "best estimate" of 15.6 ppb.

Formula 8: Derived from 1996 data set, using lakes without any significant blue-green algae communities.

Chlorophyll-a (ppb) = 1.511(Biovolume (mm^3/L)) + 4.71

For an algal biovolume of 6.209 ppm, the ± 95% confidence interval is 8.0-to-20.2 ppb of chlorophyll-a, with a "best estimate" of 14.1 ppb.

Formula 9: Derived from 1996 data set, using lakes supporting significant blue-green algae communities.

Chlorophyll-a (ppb) = 1.885(Biovolume (mm^3/L)) + 5.69

For an algal biovolume of 5.946 ppm, the ± 95% confidence interval is 6.4-to-27.4 ppb of chlorophyll-a, with a "best estimate" of 16.9 ppb.

The three example biovolumes, presented in Formulae 7-to-9, represent the biovolume that most likely describes 10,000 cells/mL, for each group examined. This relationship will be discussed in the next section. As for the first six equations, the example cell count of 10,000 cells/mL (represented by an equivalent biovolume in all three cases) describes a lake in the "fully eutrophic" category, although in the middle of the category rather than the low end. Lakes supporting significant blue-green algae communities should tend to have slightly higher chlorophyll-a concentrations than lakes with similar cell counts/biovolumes but dominated by species other than blue-green types, according to these three equations.

Algal Biovolume Versus Algal Cell Counts

Data from the 1996 sampling year were available for this analysis. Table A3 lists the non-parametric correlation coefficients and the level of significance. A positive and highly significant relationship existed between algal biovolume and algal cell count. As noted in the previous two sections, lakes with a significant blue-green algae community tend to have a slightly stronger relationship between cell counts and biovolume than lakes lacking a significant blue-green algae component.

Three equations were derived from the 1996 data that relate algal cell counts to calculated biovolume. These three equations follow Table A3. The three "best estimate" values, for the three data sets, correspond to a cell count of 10,000 cells/mL the biovolume values used in the previous section. The equations in this section are most valuable in instances where a biovolume is needed, but the sample can't be re-analyzed (i.e., cell count data from several years past).

Table A3. Non-parametric Spearman rank-order correlation coefficients and related information for a comparison of algal biovolume calculations and algal cell counts.

Time Period And Algae Type	Correlation Coefficient (r)	Degrees of Freedom	Level of Significance
1996 Only All Data	+0.87	50	P<0.001
1996 Only Non Blue-Green Lakes	+0.75	30	P<0.001
1996 Only Blue-Green Lakes	+0.88	18	P<0.001

Formula 10: Derived from 1996 data set.

Biovolume (mm^3/L) = 0.070(@sqrt(Cell Count (no./mL))) - 0.844

For an algal cell count of 10,000 cells/mL, the $\pm$ 95% confidence interval is 3.9-to-8.4 ppm of biovolume, with a "best estimate" of 6.160 ppm.

Formula 11: Derived from 1996 data set, using lakes without any significant blue-green algae communities.

Biovolume (mm^3/L) = 0.069(@sqrt(Cell Count (no./mL))) - 0.736

For an algal cell count of 10,000 cells/mL, the $\pm$ 95% confidence interval is 2.2-to-10.2 ppm of biovolume, with a "best estimate" of 6.209 ppm.

Formula 12: Derived from 1996 data set, using lakes supporting significant blue-green algae communities.

Biovolume (mm^3/L) = 0.071(@sqrt(Cell Count (no./mL))) - 1.150

For an algal cell count of 10,000 cells/mL, the $\pm$ 95% confidence interval is 0.6-to-11.3 ppm of biovolume, with a "best estimate" of 5.946 ppm.